

Up-Date on 3-D Building and other Non-Traditional Building Choices

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Virginia Center for Housing Research | Virginia Tech



3DCP | Overview

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At the Virginia Center for Housing Research (VCHR) at Virginia Tech, we focus on:

- Application of innovative technologies within the construction industry:

- Commercialization modeling
- Adoption and diffusion modeling
- Technology transfer
- Supply chain and stakeholder integration
- Business process modeling

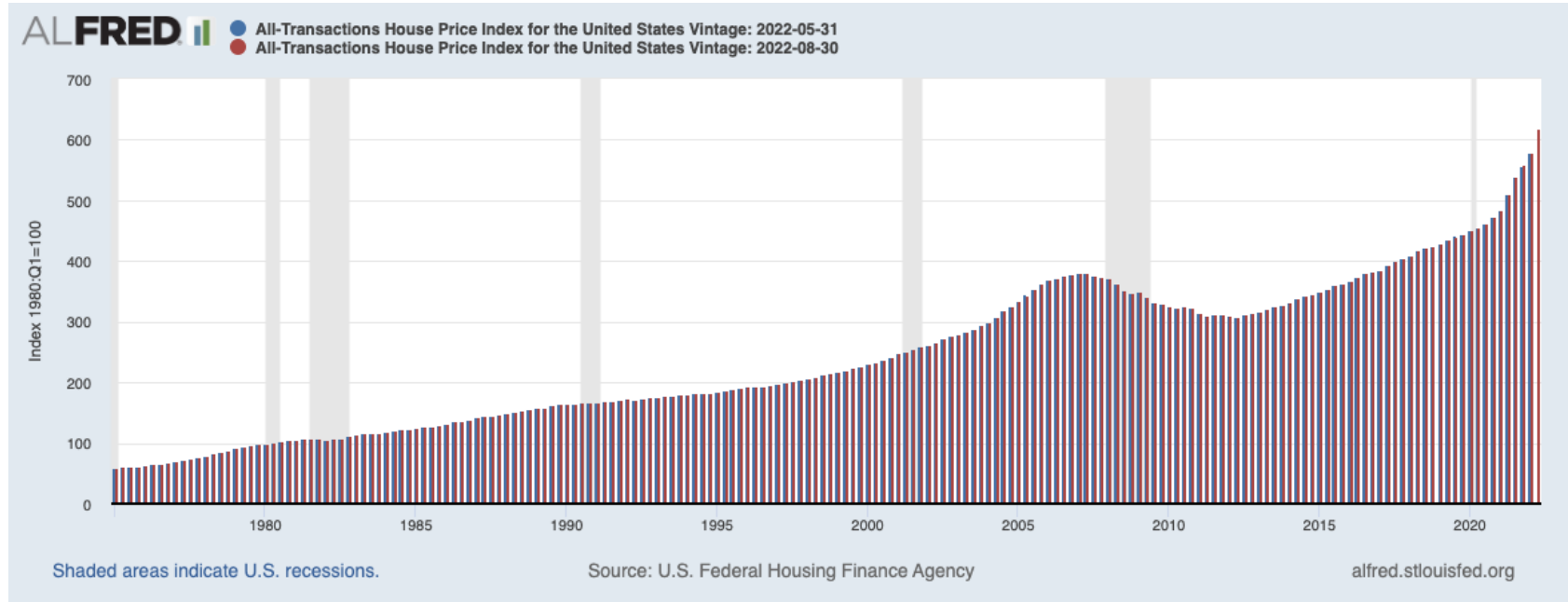
- Leveraging innovative technologies in the production and operation cycles of residential construction towards affordability:

- Remote monitoring and verification (BDL)
- Technology-integrated design and construction processes (3DCP)
- Integration of additive manufacturing (AI Space Factory))
- Integration of industrial systems (MASS & Bermuda Estates)

3DCP | Background

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US House Pricing Index from 1990 - 2022

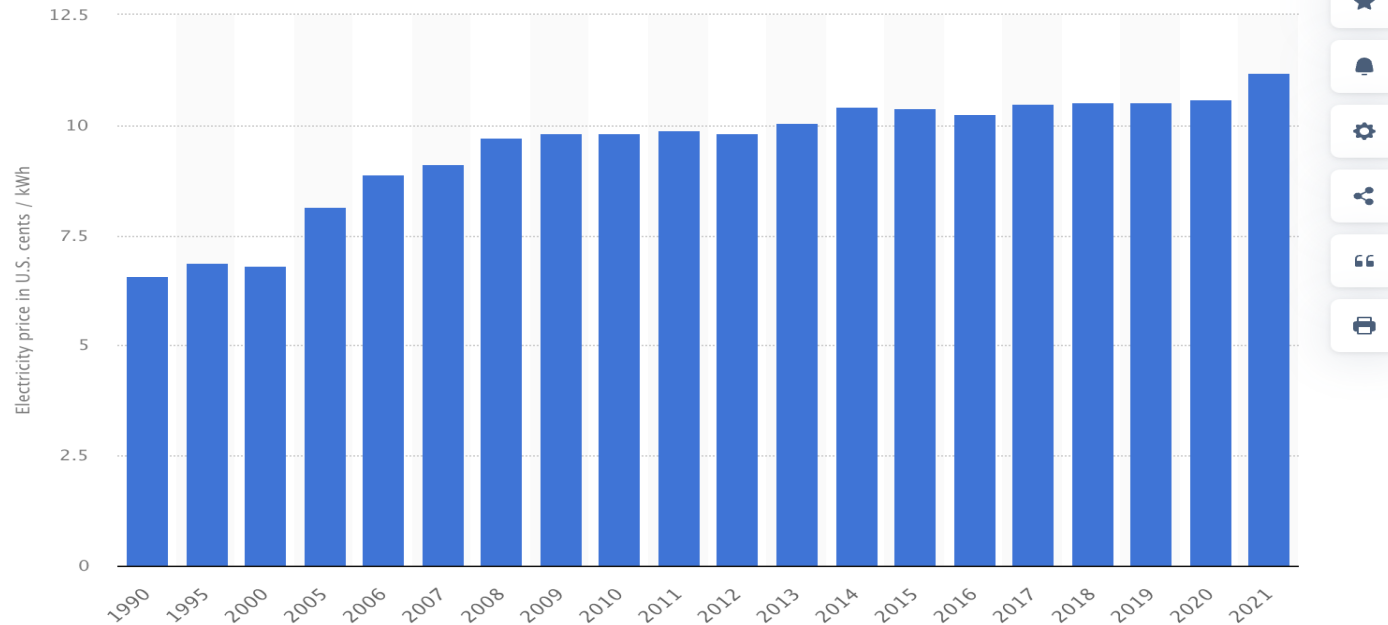


The FHFA HPI is a broad measure of the movement of single-family house prices and a weighted, repeat-sales index, meaning that it measures average price changes in repeat sales or refinancings on the same properties. The FHFA HPI serves as a timely, accurate indicator of house price trends at various geographic levels.

3DCP | Background

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Average retail electricity prices in the United States from 1990 - 2021 (in U.S. cents per kilowatt hour)



[Additional Information](#)

Source: Statista.com

© Statista 2022

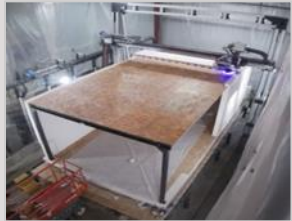
[Show source](#)

Why technology + Affordability?

- ✓ Housing Costs (owning or renting) should be 30% of income
(more= cost burdened)
- ✓ Housing Costs= (Owning or Renting) Payment + Utilities +
Healthcare/Childcare + Transportation.....
- ✓ All costs have been rising, NOT JUST electricity
- ✓ Industry land, labor, manufacturing and material costs are also
rising....

3D CONCRETE PRINTING | INTERNATIONAL MARKET RESEARCH

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DESIGN CONSIDERATIONS

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- Single Family *Affordable* Housing
- Appropriate scale for neighborhood
- 1400-1500 sf (3 Bed, 2 Bath)
- High Performance & MEP optimization
- 3D Printing Specifications (printer's module, wall height, wall thickness, wall detail, layer thickness, etc.)



Conceptual
Design

Design Team



Architect



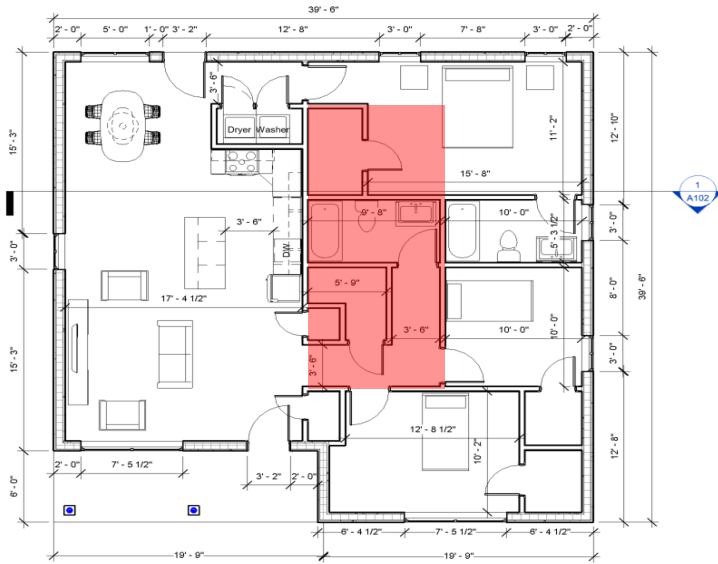
Structural Engineer



Construction Company
& Design Assist

DESIGN ALTERNATIVES | CONCEPT

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- ✓ Effective circulation.
- ✓ Effective use of space.
- ✓ Optimized MEP.



SYSTEMS INTEGRATION AND PERFORMANCE

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MECHANICAL

Heating + Cooling System:

- ✓ 12 kbtu/h ducted heat pump
- ✓ ducts within conditioned space
- ✓ ducts sealed (<6%) and insulated to R4
- ✓ supplemental dehumidifier

Ventilation System:

- ✓ Energy Recovery Ventilator
for fresh air and bathroom exhaust
- ✓ Range exhausted to exterior

SYSTEM COMMISSIONING



PLUMBING

Domestic Water System:

- ✓ 50 gal electric water heater
- ✓ PEX distribution systems
- ✓ WaterSense (low-flow)
fixtures



ELECTRICAL

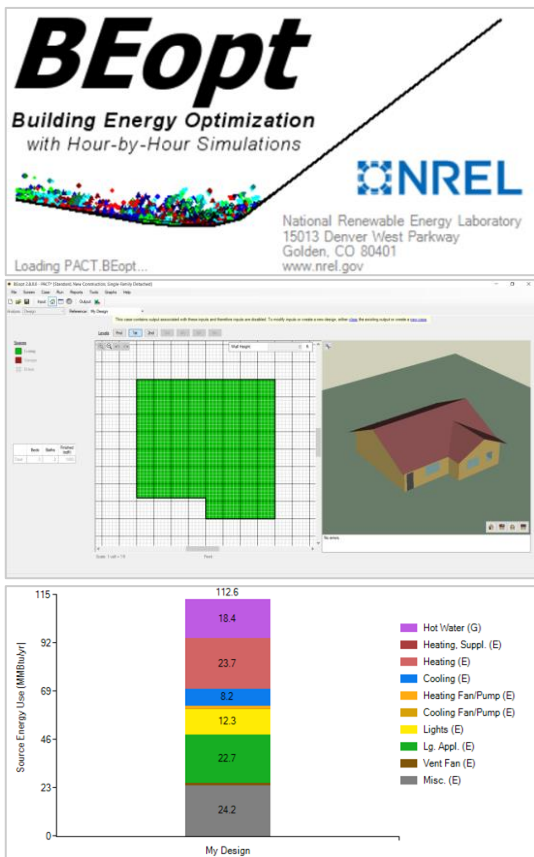
Service System:

- ✓ 200 amp panel
- ✓ panel located on interior wall
- ✓ Energy Star Lights and
Appliances

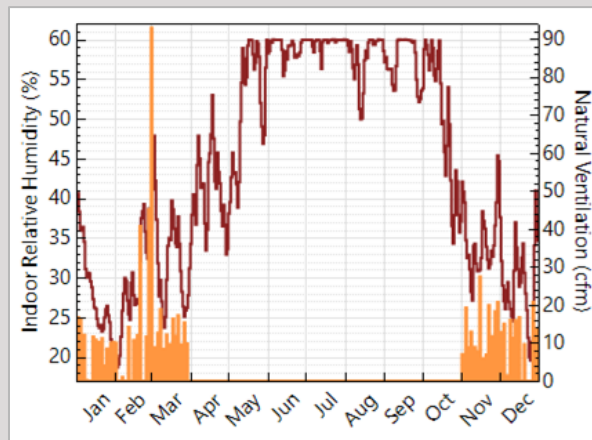


BUILDING PERFORMANCE SIMULATION | ENERGY USE

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- ✓ **Overview:** dynamic simulation (models 8,760 hours/yr),
- ✓ **Goal:** predict energy use and evaluate economic factors (net-present value, return on investment), probabilistic modeling of indoor environment (temperature, relative humidity, moisture buffering)



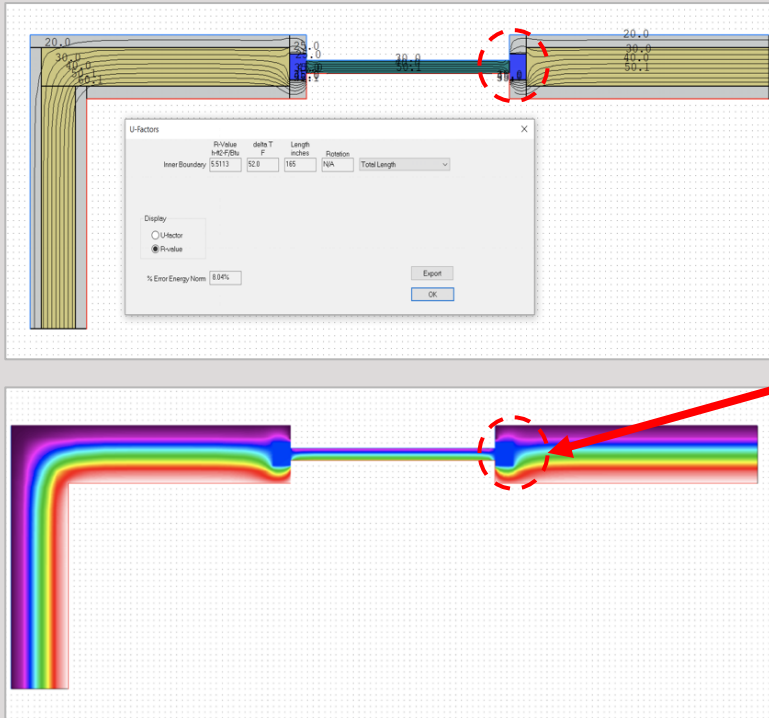
Team Lead: Armin Yeganeh, PhD student

PHASE 0: PLANNING

PHASE 1: PRE-CONSTRUCTION

PHASE 2: CONSTRUCTION

PHASE 3: POST-CONSTRUCTION



✓ **Goal:** understand thermal performance of the enclosure; identify thermal bridges

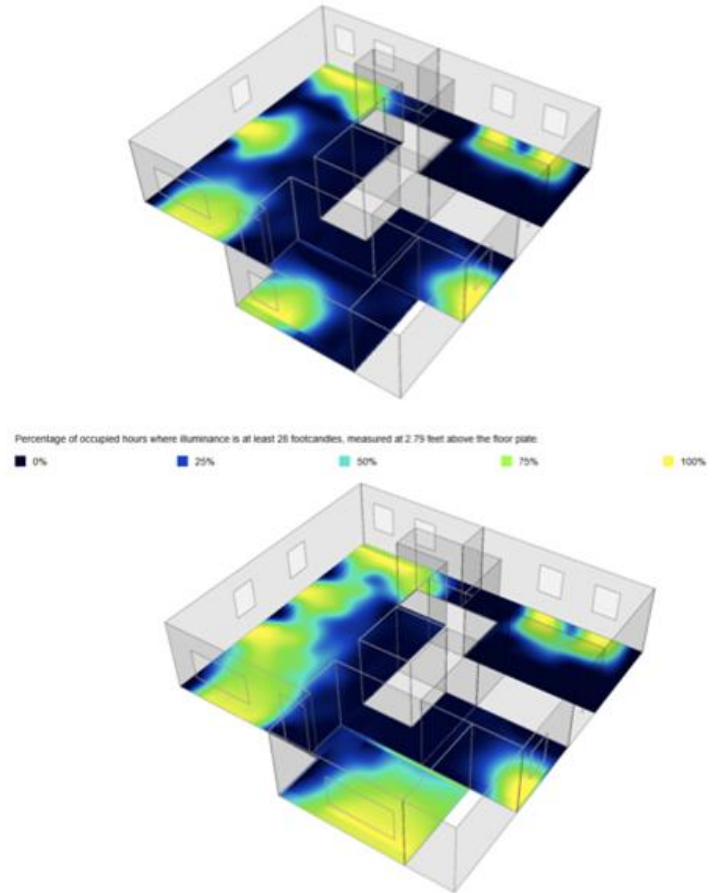
✓ **Impact:** comfort and energy use

✓ **Result:** **window-wall intersection** represents *significant thermal bridge* (will adapt detail)

Team Lead: Yash Parmar, M.S. Student

- ✓ **Goal:** Evaluate visual comfort with daylighting analysis integrated in common CAD-based design software(s)
- ✓ **Impact:** enhanced indoor environmental quality
- ✓ **Result:** informs window size and placement

Team Lead: Dr. Leila Nikdel

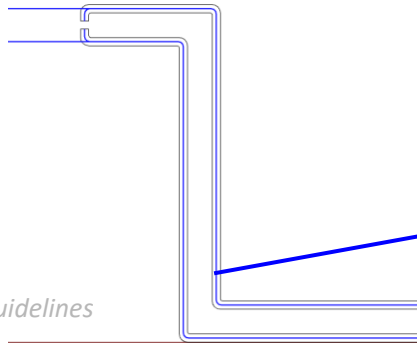


3D Printing Simulation

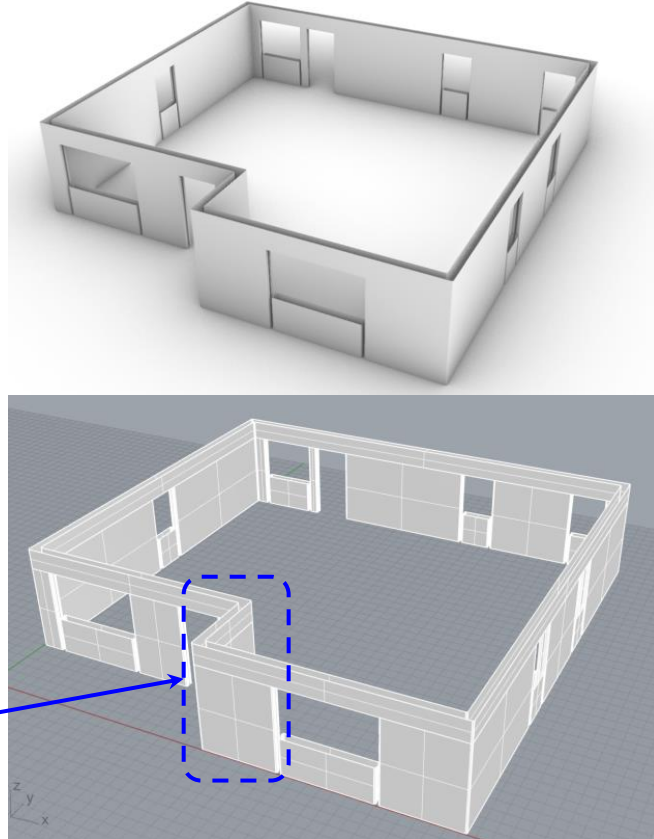
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Modeling process

- ✓ Model in **surfaces** (not solids)
- ✓ Surfaces should represent the **centerlines** of the wall.
- ✓ Export model to .STP or .IGS format
- ✓ Import .STP model to COBOD Slice for simulation



Reference: COBOD general guidelines



3D Printing Simulation

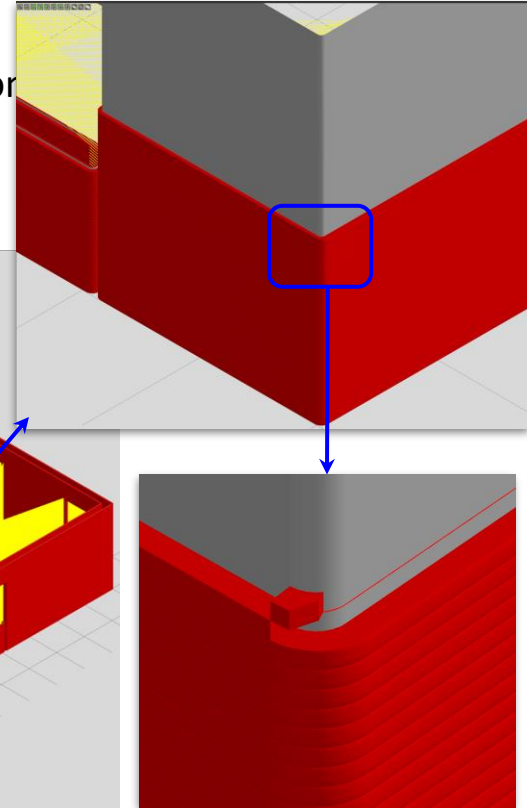
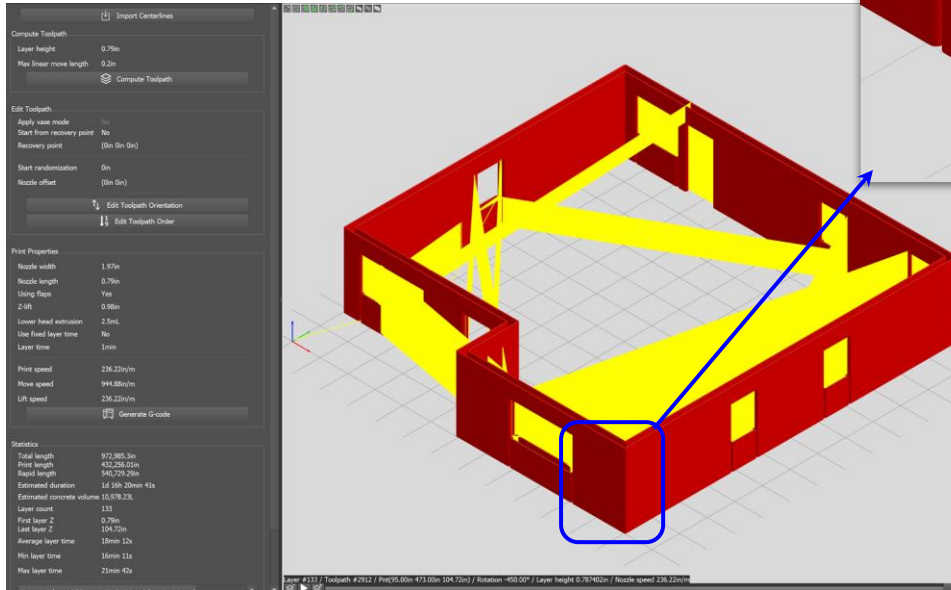
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COBOD Slice Simulation- Application

Computes Toolpath- Timing, Layering, Tool Direction

Overall- Calculates concrete volume and time

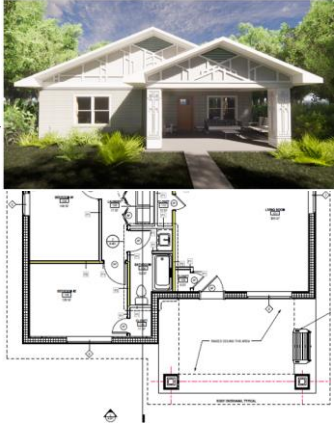
Generates G-code: used for 3D printing



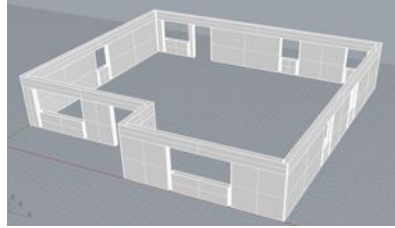
DESIGN FOR 3D PRINTING

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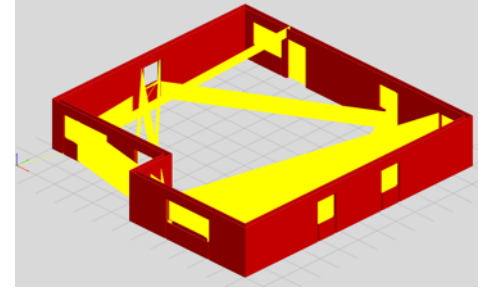
Drawings & BIM



Surface Modeling



3D Printing Simulation [STP file](#)



Optimization

Actual 3D Printing



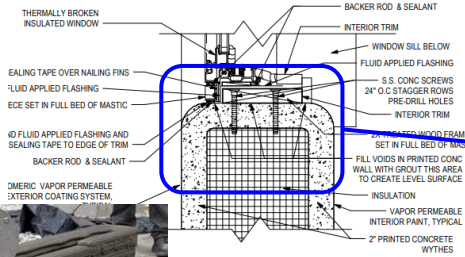
Computer numerical Control [G-Code](#)



DETAILED DESIGN

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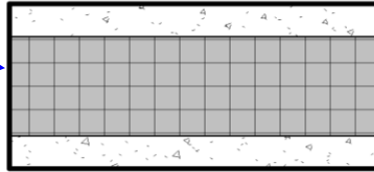
Exterior Wall Design



MB DETAIL

BIM Modeling Limitations

Plan



Type: 3D Printed Wall - 10"

Total thickness: 0' 10"

Resistance (R): 25.2763 (h-ft²-°F)/BTU

Thermal Mass: 7.7626 BTU/°F

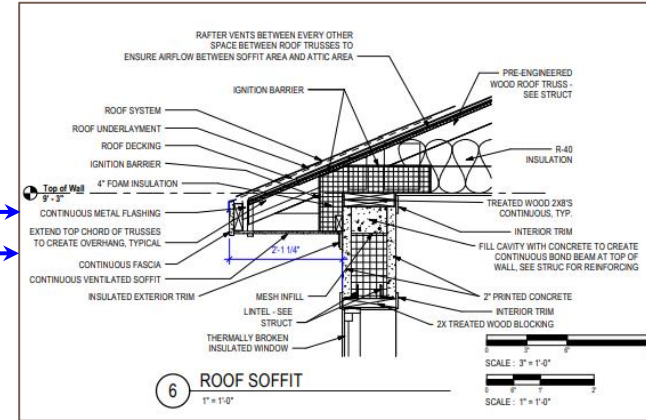
Sample Height: 20' 0"

Layers

EXTERIOR SIDE					
	Function	Material	Thickness	Wraps	Structural Material
1	Core Boundary	Layers Above Wrap	0' 0"		
2	Structure [1]	Concrete, Cast-in-Place	0' 2"		<input checked="" type="checkbox"/>
3	Thermal/Air Layer [3]	Rigid insulation	0' 6"		<input type="checkbox"/>
4	Structure [1]	Concrete, Cast-in-Place	0' 2"		<input type="checkbox"/>
5	Core Boundary	Layers Below Wrap	0' 0"		

INTERIOR SIDE

Insert Delete Up Down

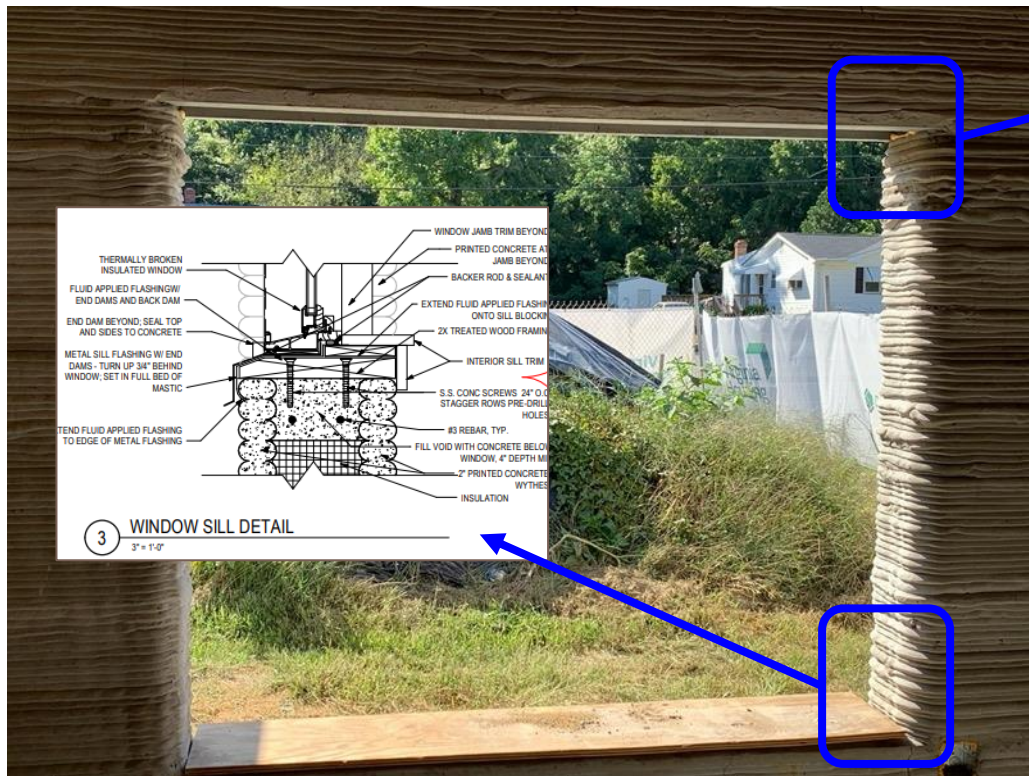


Wall Section

DETAILED DESIGN

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Wall Openings & Lintel Beams



PROJECT 1 (CONT.) | RICHMOND, VA

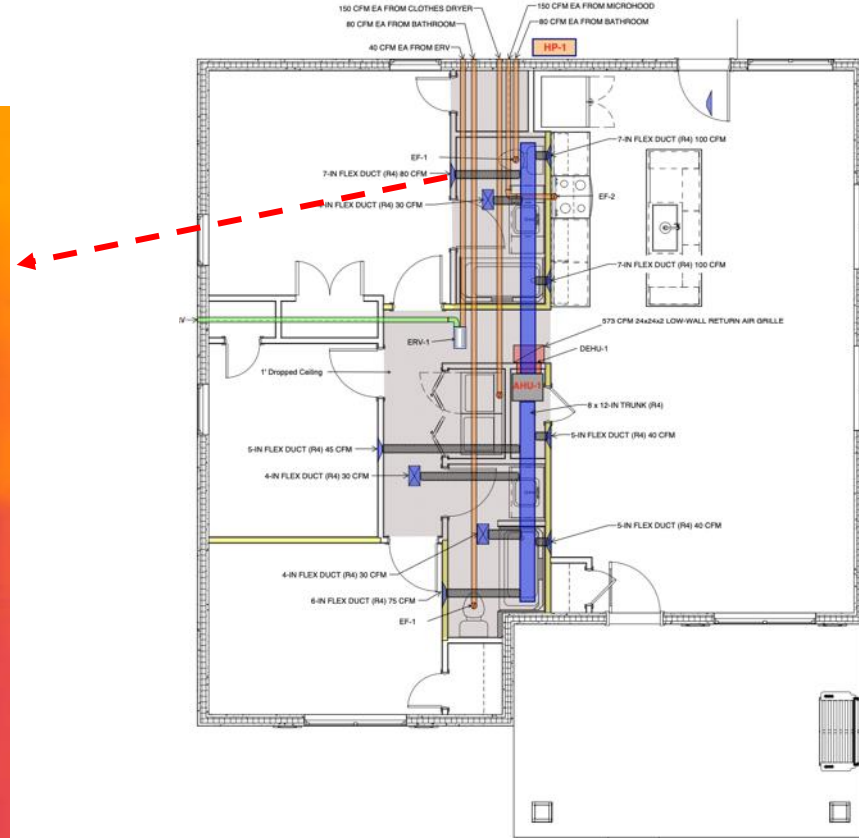
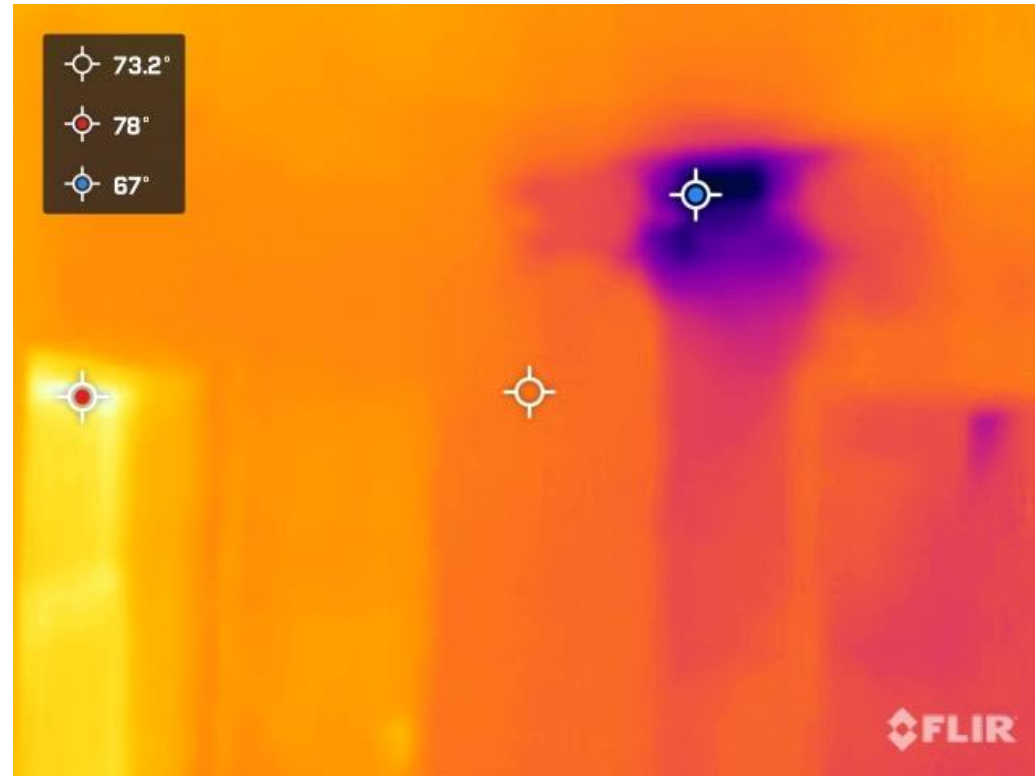
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PROJECT 1 (CONT.) | RICHMOND, VA

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SUPPLY AIR DIFFUSER COVERED BY DRYWALL



PROJECT 1 | RICHMOND, VA HOUSE

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Estimated Energy Cost: \$1,246/yr

**~43% more efficient than U.S.
Avg.**



Enclosure Tightness: 3.6 ACH₅₀

PROJECT 2 | PENINSULA AND GREATER HABITAT FOR HUMANITY

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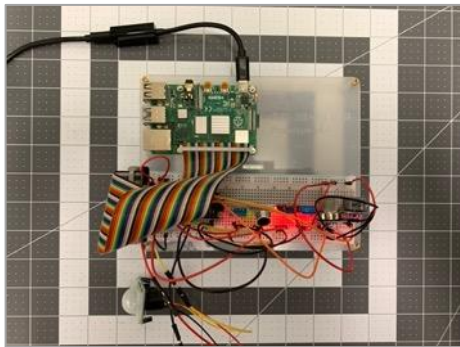
Estimated Annual Cost

HEATING	\$333
COOLING	\$103
WATER HEATING	\$215
LIGHTS & APPLIANCES	\$439
SERVICE CHARGES	\$79
TOTAL COST:	\$1,170

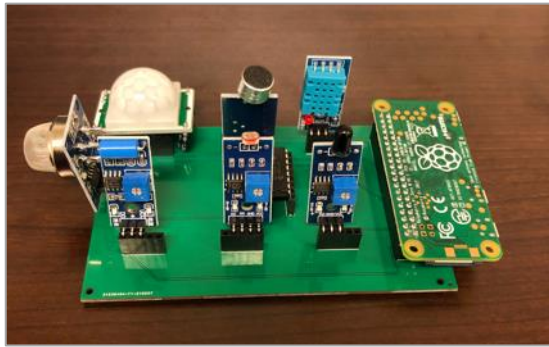


✓ **Estimated Energy Costs:** 47% more efficient (or saves \$1,026/yr) compared to avg U.S. Home

PROTOTYPE V1



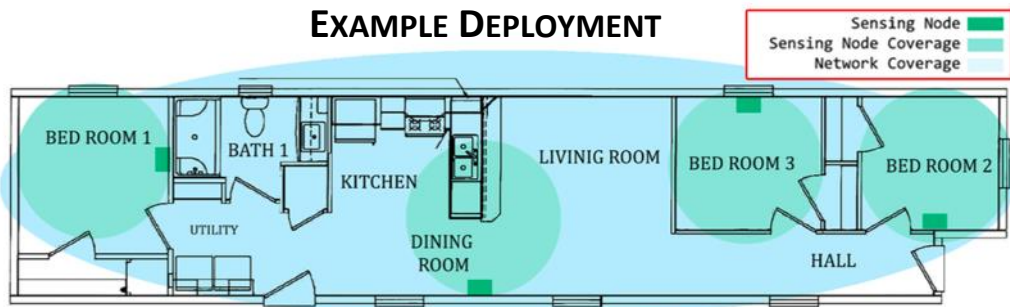
PROTOTYPE V2



PROTOTYPE V3



EXAMPLE DEPLOYMENT



BUILDING DATA LITE | SENSOR DEVELOPMENT

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Dr. Xinghua Gao

1. Motion
2. Temperature
3. Humidity
4. Air pressure
5. Lighting
6. Sound (high, medium, and low frequency)
7. Oxidizing gases (NO, NO₂, etc.)
8. Methane, Ammonia, Hydrogen, Propane, Ethanol, etc.

The system is customizable and has more sensing capacities



BERMUDA ESTATES | CHESTERFIELD, VA

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✓ 50 units, Scope: unit repair + replacement with enhanced units

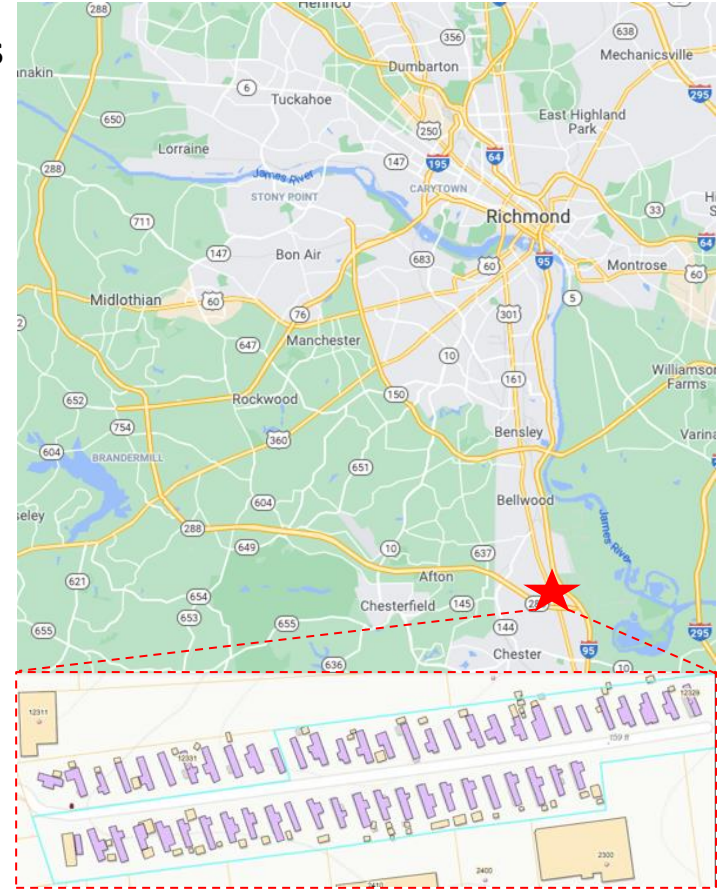
2021 REPORT TO THE COMMUNITY



Improving Lives in Bermuda Estates

"project:HOMES rescued us," said Bonnie Newton, a resident of the Bermuda Estates Manufactured Home Community in Chesterfield County.

In September 2020, project:HOMES purchased Bermuda Estates Manufactured Home Community with equity partner VCDC, to enhance the quality of life for existing residents, prevent displacement and eliminate the stigma associated with manufactured housing communities. Support from the Bob & Anna Lou Schaberg Foundation allowed project:HOMES to make the necessary down-payment on the property. The redevelopment of Bermuda Estates includes major infrastructure improvements, home repairs at no cost to residents, unit replacement, community engagement and a Community Resource Center.



INTERVENTION | ADAPT MANUFACTURED HOUSING

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50 existing units:

- 1973-2000 vintage
- Durability issues
- High utility costs
- Not affordable



[Stock] Factory Units:

- Heating only
- Open crawlspace
- Added hardiplank siding



Enhanced Units:

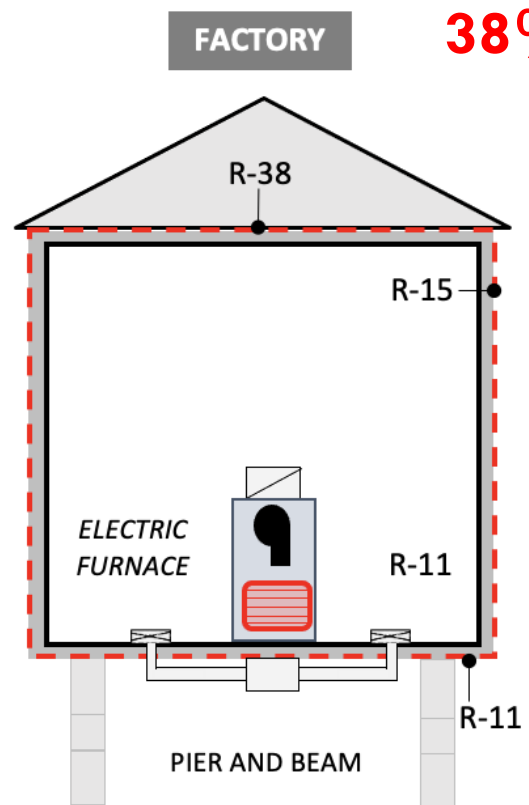
- Added porch & gutters
- Added central air conditioning
- Added conditioned crawlspace

ENCLOSURE TESTING | AIR LEAKAGE

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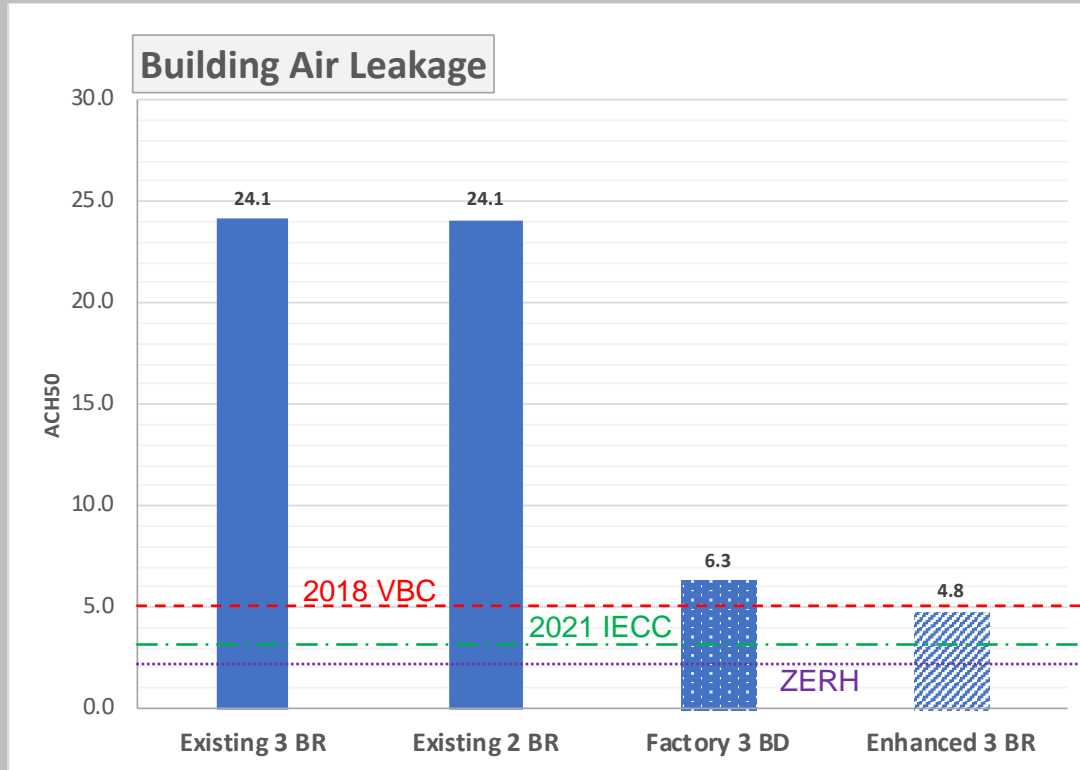


DUCT TESTING | AIR LEAKAGE



BUILDING AIR LEAKAGE | RESULTS

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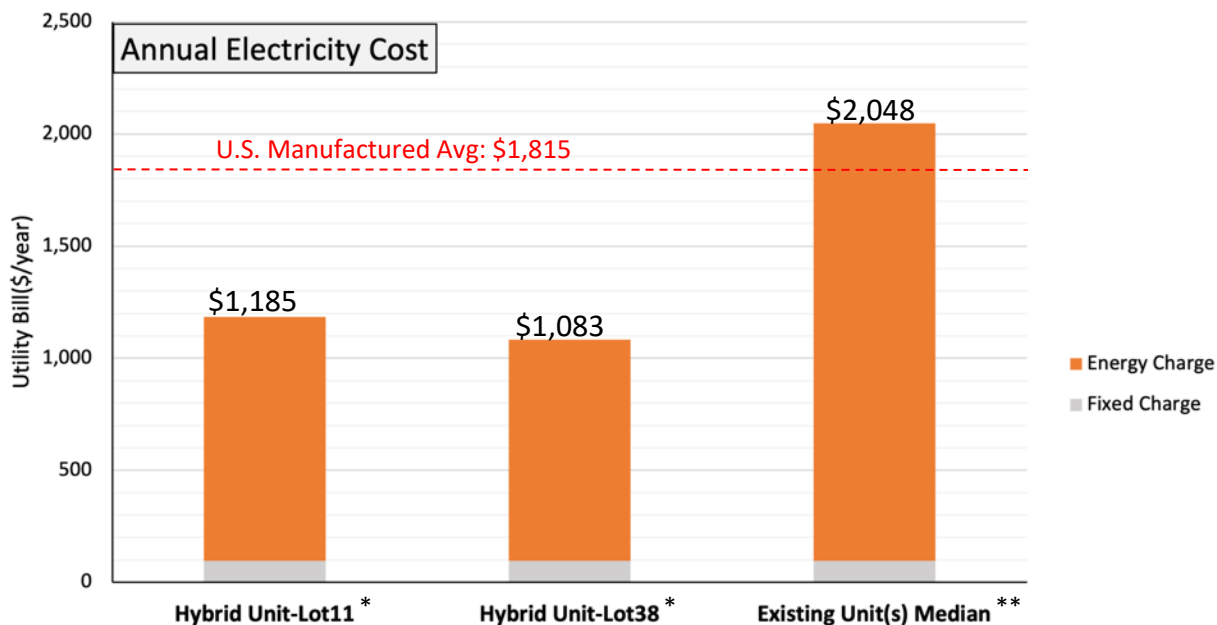


projectHOMES innovation:

- ✓ 80% tighter: existing unit avg
- ✓ 24% tighter: factory unit
- ✓ 4% tighter: VA building code requirement

ANNUAL ELECTRICITY COST SAVINGS

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* Data source: U.S. Dept. of Energy Simulation

** Data source: resident electricity bills

projectHOMES innovation:

- ✓ **38% savings (\$681/yr)** compared to avg. U.S. manufactured housing¹
- ✓ **45% savings (\$914/yr)** compared development median

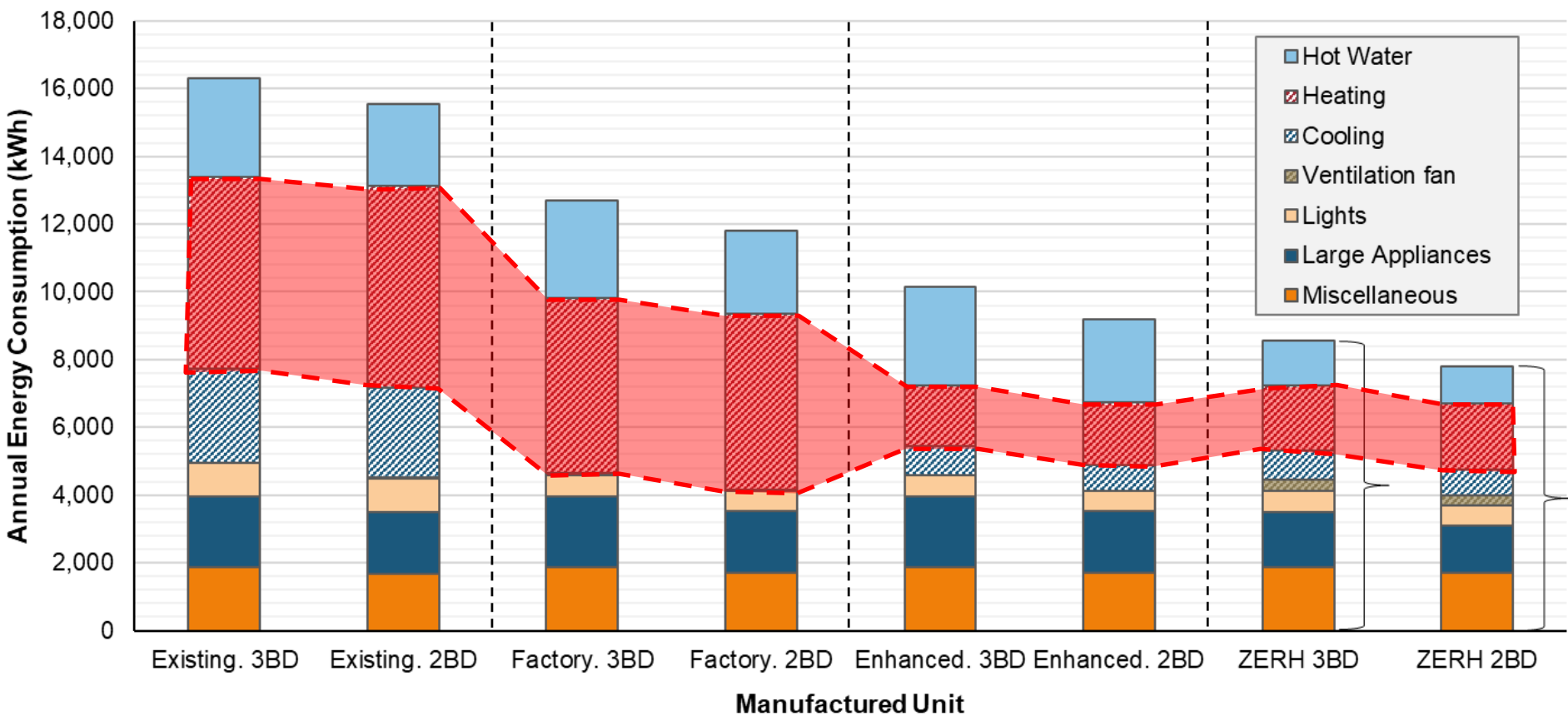
¹Source: U.S. EIA, 2011; normalized in 2022 dollars

ENERGY MONITORING

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ENERGY SIMULATION | BEOPT



AFFORDABILITY IMPACT | RICHMOND, VA MSA

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	ENERGY BURDEN							
Annual Energy Cost	Existing		Factory		Enhanced		Net-zero Ready	
	3BD	2BD	3BD	2BD	3BD	2BD	3BD	2BD
	\$1,804	\$1,720	\$1,496	\$1,452	\$1,179	\$1,077	\$1,048	\$965
100% AMI (\$68,324)	2.6%	2.5%	2.2%	2.1%	1.7%	1.6%	1.5%	1.4%
50% AMI (\$34,162)	5.3%	5.0%	4.4%	4.3%	3.5%	3.2%	3.1%	2.8%
30% AMI (\$20,497)	8.8%	8.4%	7.3%	7.1%	5.8%	5.3%	5.1%	4.7%

Energy burdened: > 3% gross income spent on energy

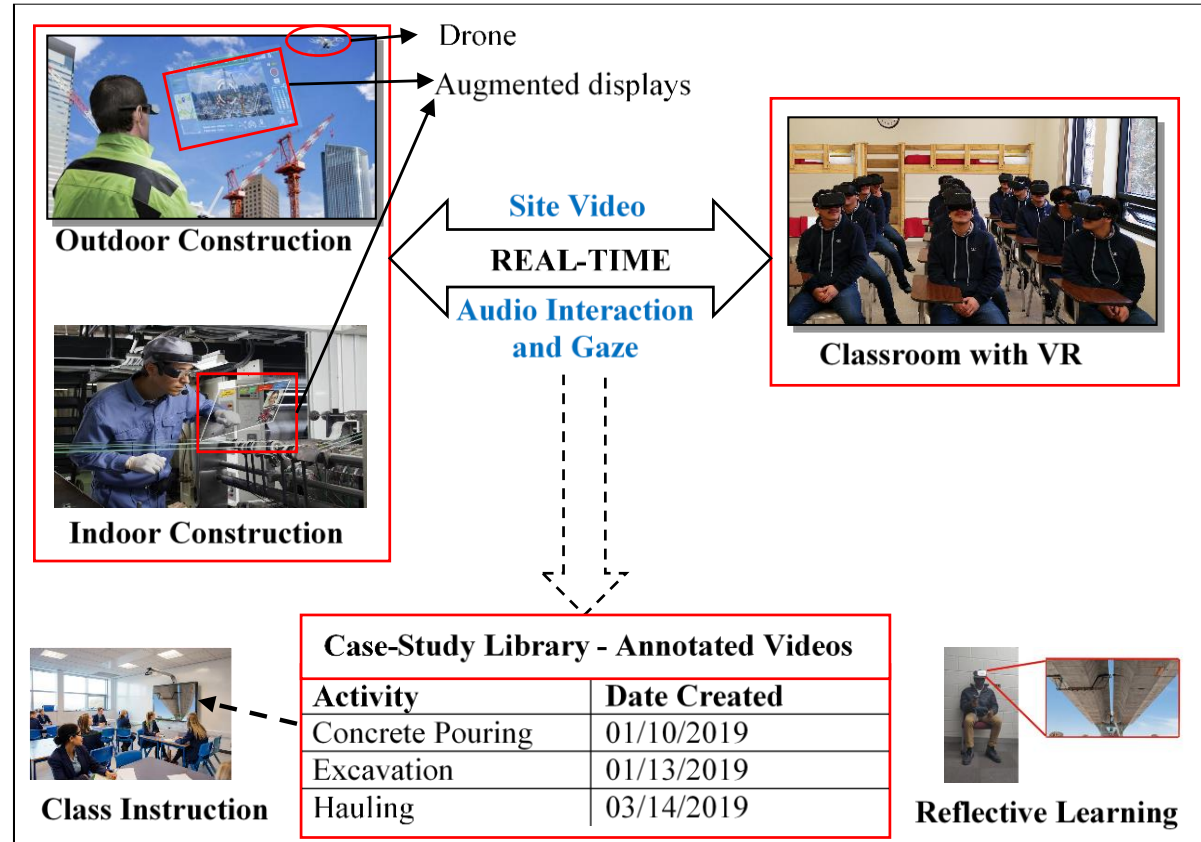
High energy burden: > 6% gross income spent on energy

FUTURE

- VR/AR IN CONSTRUCTION
- ROBOTS
- AUTOMATED MANUFACTURING &
CONSTRUCTION TASKS
- PRINTING FOR EXTREME ENVIRONMENTS

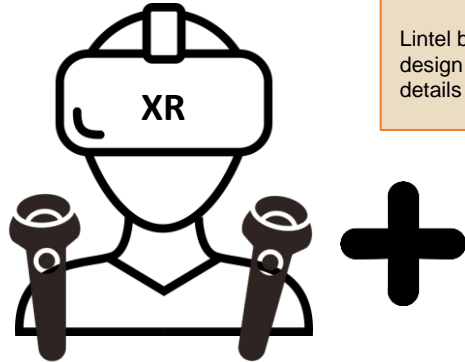
Objective:

- ✓ Develop a cyber-learning tool capable of providing authentic outdoor and indoor construction site visit experiences
- ✓ Real-time bi-directional communication between construction professionals in the field and students in the classroom.



Principles of 3D Concrete Printing

XR App for Interactive Learning



3DCP Training using
extended reality (XR) and
virtual walkthrough

Learning in an Immersive Environment



Lintel beams
design and
details

3DCP
connection to
roofing
details



Bottom of
window
printing
specifications

Slab on grade
details.
Footings
design

VT CDR- Digital Fabrication

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Dr. Nathan King and Professor Robert Dunay



VT Center for Design Research

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VT CDR- Digital Fabrication

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VT CDR- Digital Fabrication

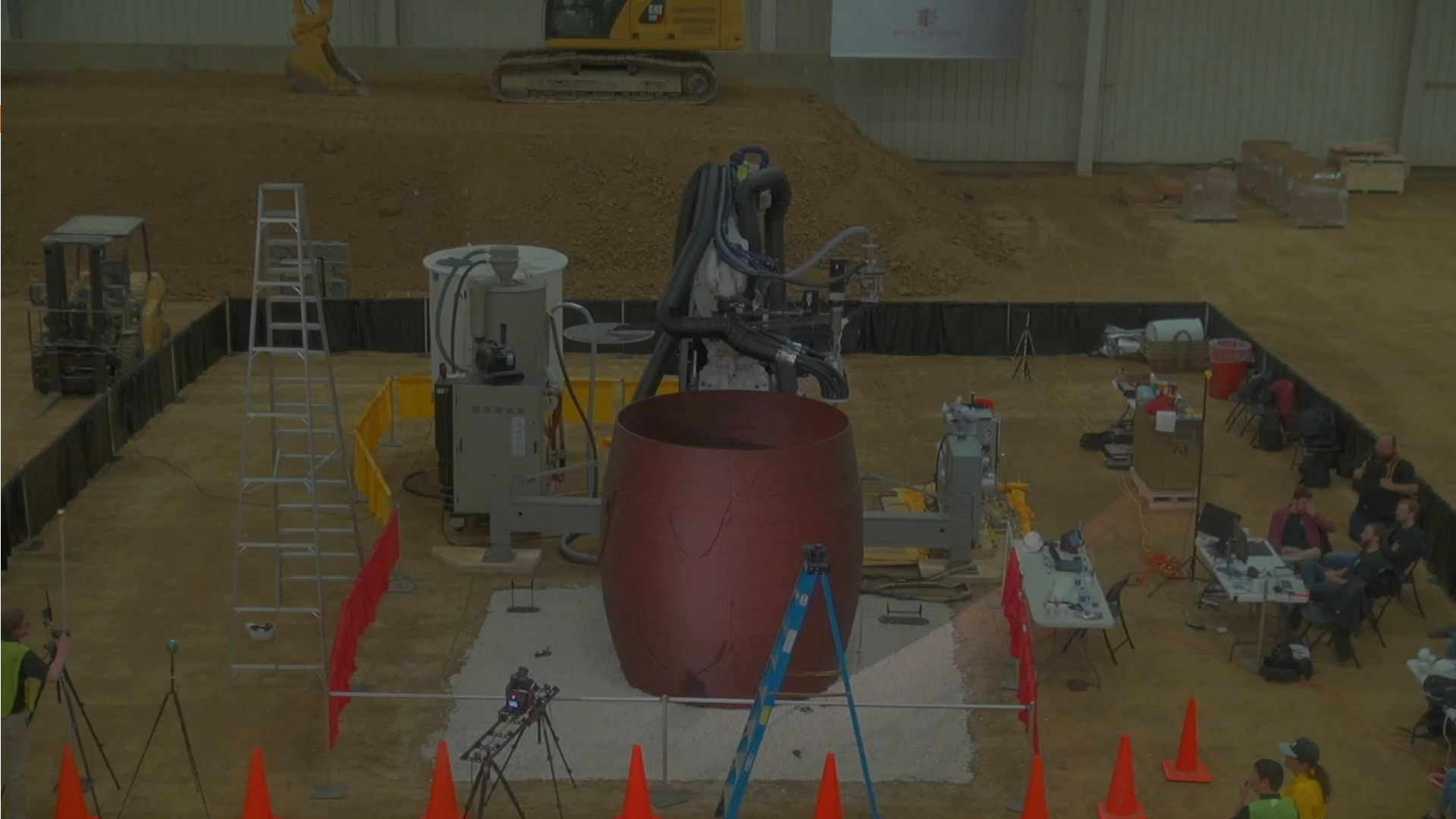
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VT CDR- Digital Fabrication

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VT Mechanical Engineering- Drone Technology

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